A Study on Contouring Motion Control of Machine Tools

First Report: Analysis of Dynamic Motion Error

Kyoto University 〇Cefu HONG Mitsubishi Electric Corp. Kotaro NAGAOKA
Ricoh Co., Ltd. Atsushi IIZUKA Kyoto University Atsushi MATSUBARA, Soichi IBARAKI

In our research, we analyze control methods to obtain high accuracy synchronous motion in feed-drive system of machine tool. First, we present the definition of contouring motion error for error diagnosis. Second, the influences of the command and control characteristics on the dynamic contouring errors are analyzed by using magnified error profile. Then, a diagnosis method with the square motion is proposed and carried out in the experiment.

1. Introduction

In recent years, there is an increasing need for high precision products such as mould for optical components, which require both high machining accuracy and high machining efficiency. Especially when machining mould with free-form surface, high-accuracy contouring control with synchronously driving multiple linear axes is indispensable. The contouring accuracy in multi-axis synchronous motion is clearly more difficult to improve than the motion accuracy of a single axis, because much more factors affect it[1]. For obtaining high-accuracy contouring control, it is necessary to clarify how each error factor affects motion of feed-drive system.

The objective of this research is to analyze a control method for high precision synchronous motion control of machine tool. To this goal, this paper will first present a definition of contouring motion error for error diagnosis, second, analyze the influences of the command and control characteristics on the dynamic contouring errors by using magnified error profile. Then, a diagnosis method with the square motion is proposed and is carried out in the experiment.

2. Definition of contouring motion error

Typically, contouring motion error vector is defined as a vector from the nearest point in a command trajectory to the actual position. Kweon et al.[2] presented an algorithm for determining the contouring motion error vector for a smooth command trajectory. However, when a command trajectory is unsmooth (i.e. when a command trajectory is given by (x(t), y(t)), either or both of the derivative of x(t) and y(t) is discontinuous at some t), as is shown in Fig.1 (a), the magnified error profile would be overlapped around a bisector at the unsmooth point. Such an unsmooth change at a corner would make the magnified error profile unclear and cause problem in error diagnosis.

To address this issue, some of the authors[3] proposed a scheme to magnify contouring motion errors such that the magnified error profile is continuous even when the command trajectory is unsmooth. This scheme is referred to as the Offset-path Method in this paper. Fig.1 (b) shows the magnified error profile plotted by using Offset-Path Method.

3. Error patterns with magnified error profile

Dynamic contouring motion error is caused by many factors such as delay, vibration or friction accompanying with feed-drive motion. Generally, the dynamics of feed drive would affect motion accuracy dominantly when velocity increases, especially in high-speed machining. Dynamic error is focused on in this research.

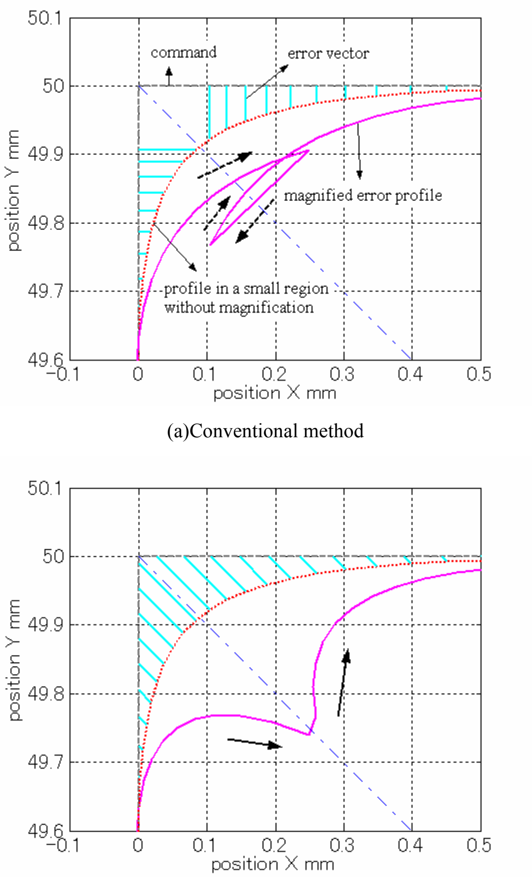
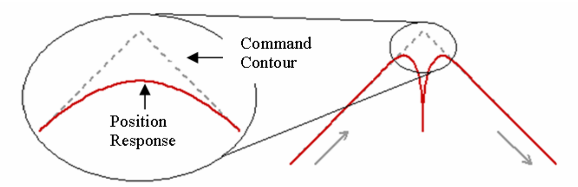


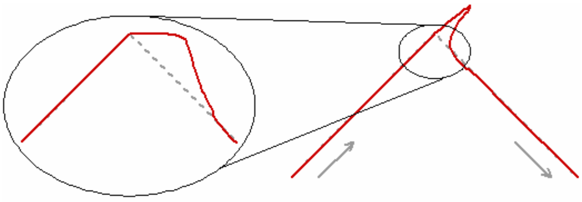
Fig.1 Motion trajectory with magnified contouring error

Fig.2 (a) shows the undershoot at a corner caused by the delay in servo response. In Fig.2 (a), the right plot shows the magnified error profile calculated by applying Offset-path Method. The left plot shows the actual position trajectory in a small region around the corner. Typically a filter such as S-shape filter is applied to reduce impact on machine tool over the acceleration (deceleration) period, which causes servo delay. To improving the efficiency in multi-axis synchronous control, a servo control system often starts accelerating one axis while the other axis is decelerating, which causes undershoot at a corner. Fig.2 (b) shows the influence of stick motion, which is incurred by Coulomb friction. When one axis reverses, it does not immediately starts moving to the opposite direction until it overcomes the friction. Fig.2 (c) shows the influence of the difference in the dynamics of X and Y axis. When going through corner, contouring motion error appears as ripples.

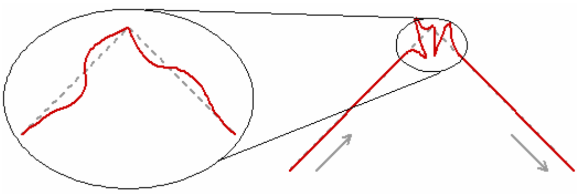
Comparing with undershoot at corner, the influence of stick motion and the influence of the difference in the dynamics of X and Y axis is more difficult to identify. Therefore, by changing dynamics in X and Y axis, contouring motion error at corner is analyzed.



(a)Undershoot at corner caused by servo delay



(b)Influence of stick motion



(c)Ripples caused by the difference in the dynamics of X and Y axis

Fig.2 Error factors appeared on the magnified error profile

4. Experimental case study

To experimentally study the influence of error factors presented in the previous section, a contouring motion error was measured on a small experimental test stand of 3-axis machine tool. A diamond-shaped command trajectory is given, as is shown in Fig.3. The feedrate is set to be 3.0m/min, acceleration is set to be 1.0m/s^2. An S-shape acceleration (deceleration) command trajectory is applied with the acceleration constant 24ms. By using data logging function in CNC, the position of each axis measured by a linear encoder is sampled to evaluate contouring motion error.

The contouring error was measured under the following two setups of the proportional gain in the velocity loop controller. 1) Case 1: the velocity-loop proportional gain is set at the same value, K_{vp}=60, for both X- and Y-axes. 2) Case 2: the velocity-loop proportional gain is set at K_{vp}=60 for the X-axis, and K_{vp}=80 for the Y-axis. Note that the friction in Y-axis is larger than in X-axis on the test stand, because of the difference in the guide way. In a commercial CNC, it is often the case that the velocity-loop proportional gain is set proportionally to the friction, such that the error caused by the stick motion becomes approximately the same for both X- and Y-axes. Although the difference in the stick motion influence is minimized in Case 2, the discussion presented in the previous section suggests that the contour error caused by the difference in X- and Y-axis dynamics would be larger in Case 2. And experiments were conducted to verify this.

Fig.4 shows magnified error profiles by Offset-path Method. From Fig.4 (a), an undershoot at all the four corners is about 20μm. The influence of stick motion is about 18μm in 1st and 3rd corner where the direction of Y-axis motion changed. While, the influence of stick motion is about 8μm in 2nd corner where the direction of X-axis motion changed. On the other hand, in Fig.4 (b), contouring motion error about 3μm appeared at the 3rd corner, which is caused by the difference in the dynamics of X and Y axis. Note that the wavy error appeared at the lines between corners is caused by pitch error of ball screw.

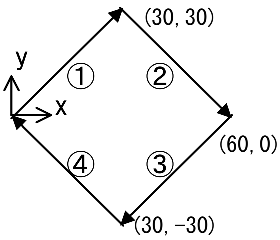
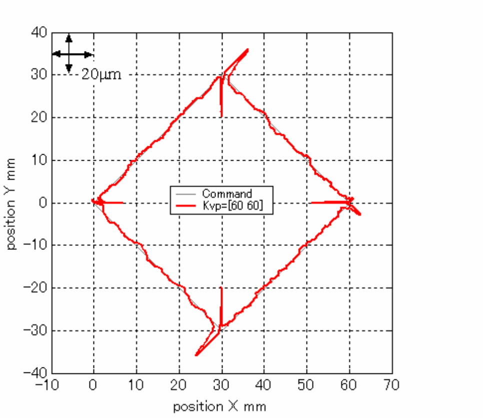
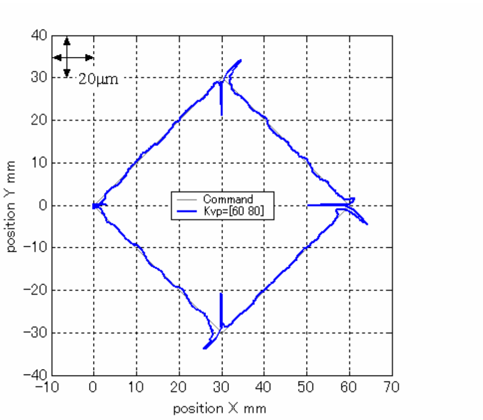


Fig.3 Command Path



(a) Case 1



(b) Case 2

Fig.4 Magnified error profiles by Offset-path Method

5. Conclusion

By using magnified error profile by Offset-path Method, error factors of dynamic contouring motion error and its diagnosis method is clarified.

References

1) Nagaoka: Control Method of Motion Error Compensation for NC Machine Tools, International Journal of Automation Technology, **3**, 3 (2009).
2) Kweon et al.: An Input-Data-Type-Free Contour Error Controller with Weighted Contour Error Components, International Conference on Leading Edge Manufacturing in 21st Century, 3(2005), pp.981-986.
3) Ibaraki, Matsubara: On the Magnification of Two-dimensional Contouring Errors by Using Contour-parallel Offsets, To be published in Precision Engineering.